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White light sources filtered with fiber Bragg gratings for RF-photonics applications

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Abstract

In this paper we demonstrate that broadband light emitters filtered with fiber Bragg gratings are a suitable light source for RF-photonics applications. A 0.075 nm bandwidth fiber grating illuminated by a light emitter of 40 nm bandwidth has been used as light source to feed a microwave phase shifter based on a chirped fiber Bragg grating. The device operates successfully in the tested frequency range (0.5–6) GHz and has been optically tuned in a range of 4 nm.

Keywords: Light sources; Fiber gratings; RF photonics

1. Introduction

Microwave-photonics systems use an optical wavelength generated by a laser source to carry a radio frequency (RF) signal through the optical components of the system [1], in particular devices based on fiber gratings such as transversal filters [2], phase shifters [3] or beamforming networks for phased arrays antennas [4] must be powered by a number of optical wavelengths equal to the number of bits in the lines [3]. Moreover, one or more tunable lasers may be needed in the case of continuous steering of chirped fiber gratings [5].

The RF-photonic device becomes complex and expensive with the increasing number of optical laser sources, in addition some kind of thermal control is required to compensate the drift of the gratings with temperature [6]. The requirements of the optical source can be simplified in several ways: optimizing the architecture of the lines [7], taking control of the distribution network with a timing unit [8], using delay lines operating with a single optical wavelength [9] or filtering a broadband source with Fabry–Perot filters [10].

In this paper we investigate the possibility of using white light sources for feeding microwave optical systems. We study a fiber optic time delay line when it is optically powered with a broadband light emitter filtered with gratings of different bandwidths. The experimental results are com-

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pared with the performance of the system when it is fed by a tunable laser. The proposed configuration has the advantage of a large optical bandwidth and a capability for multiwavelength operation although it has the inconvenient of a lower signal to noise ratio and a reduction of the microwave operating band.

2. Experimental

The configuration of the experimental set-up reported here is shown in Fig. 1. The optical light source consists of a fluorescent erbium doped fiber filtered with a fiber Bragg grating. The grating is stretched to tune the wavelength launched in the RF-photonic device. After reflection in the grating the amplitude of the light is modulated by an electrooptic modulator with the radio frequency (RF) signal supplied by the RF generator of a network analyser. The light coming out from the device under test is detected with a photodiode and the microwave signal supplied by the detector is measured with the vector network analyser. The phase $\Psi(\Omega)$ and the amplitude $E(\Omega)$ of the field generated by the photodiode in the microwave transmission line can be obtained from the transfer functions of the filter, $\rho(\omega)$, and the device under test, $H(\omega) = h(\omega)\exp(\mathrm{j}\phi(\omega))$, as:

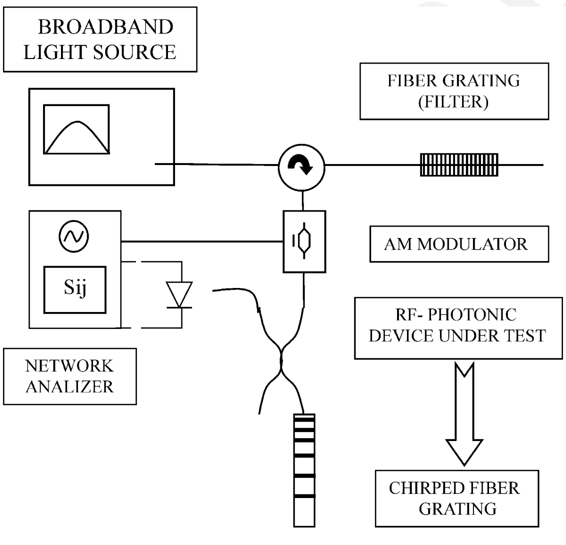

Fig. 1. Schematic diagram of the experimental set-up.

$$
\begin{aligned}
E^2(\Omega) = m^2 \Bigg\{ \Bigg(\int_{-\infty}^{+\infty} & |\rho(\omega)|^2 [h(\omega)h(\omega+\Omega) \\
& \times \cos(\phi(\omega) - \phi(\omega+\Omega)) \\
& + h(\omega)h(\omega-\Omega)\cos(\phi(\omega) \\
& - \phi(\omega-\Omega))]\,\mathrm{d}\omega \Bigg)^2 + \Bigg(\int_{-\infty}^{+\infty} |\rho(\omega)|^2 [h(\omega) \\
& \times h(\omega+\Omega)\sin(\phi(\omega) - \phi(\omega+\Omega)) \\
& - h(\omega)h(\omega-\Omega)\sin(\phi(\omega) \\
& - \phi(\omega-\Omega))]\,\mathrm{d}\omega \Bigg)^2 \Bigg\}, \qquad (1)
\end{aligned}
$$

$$
\begin{aligned}
\Psi(\Omega) = \arctan \Bigg(\int_{-\infty}^{+\infty} & |\rho(\omega)|^2 [h(\omega)h(\omega+\Omega) \\
& \times \sin(\phi(\omega) - \phi(\omega+\Omega)) \\
& - h(\omega)h(\omega-\Omega)\sin(\phi(\omega) \\
& - \phi(\omega-\Omega))]\,\mathrm{d}\omega \Bigg) \\
& \Bigg/ \Bigg(\int_{-\infty}^{+\infty} |\rho(\omega)|^2 [h(\omega)h(\omega+\Omega)\cos(\phi(\omega) \\
& - \phi(\omega+\Omega)) + h(\omega)h(\omega-\Omega)\cos(\phi(\omega) \\
& - \phi(\omega-\Omega))]\,\mathrm{d}\omega \Bigg), \qquad (2)
\end{aligned}
$$

where m is the modulation depth, ω is the optical frequency and Ω is the microwave frequency.

The photonic device under test in this experiment is a time delay line formed of a chirped fiber grating [3,5]. Three different gratings have been separately used as filters, they have 5 cm in length, uniform period and uniform index modulation amplitude. The reflectivity of the gratings is about 90% and their bandwidths are 0.075 nm (filter g1), 0.120 nm (filter g2) and 0.210 nm (filter g3). The grating used as delay line is a linearly chirped grating with cosine apodization, it has 4 nm bandwidth and 880 ps/nm dispersion. The grating used as filter is stretched to sweep its Bragg wavelength over the entire reflection band of the chirped grating. The phase and amplitude spectra of these gratings can be seen in Fig. 2.

The time delay of a 6 GHz microwave signal is shown in Fig. 3 as function of the optical wavelength selected by the filters. Since the chirped

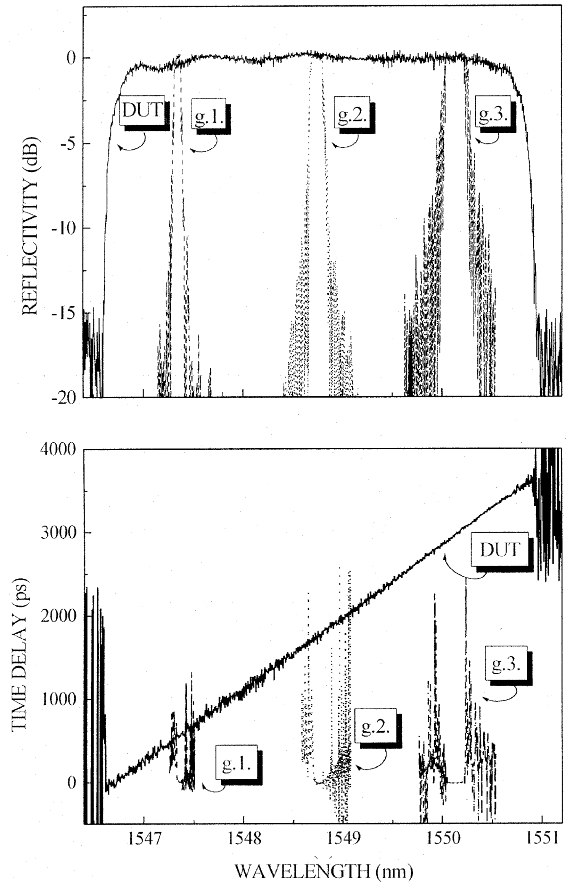

Fig. 2. Spectra of the gratings used in the experiment: (top) amplitude response; (bottom) time delay response. Gratings used as filters: g1, g2, and g3 (respective bandwidths: 0.075 nm, 0.120 nm, and 0.210 nm). Chirped grating used as delay line: DUT.

grating used in this experiment has a smooth dependence on the optical wavelength, the group delay of the microwave signal generated by the photodiode coincides with group delay of the light reflected by the grating, so the results presented in Fig. 3 are a low resolution measurement of the optical response of the chirped grating. It can be observed that the phase response of the system is independent on the filter bandwidth because the spectral variations of the device under test are negligible within the bandwidth of the filter. The use of a grating as filter has the beneficial effect of suppression of ripples in the response of the microwave device. The dispersion of the grating obtained from the three curves of Fig. 3 is 884 ± 4,

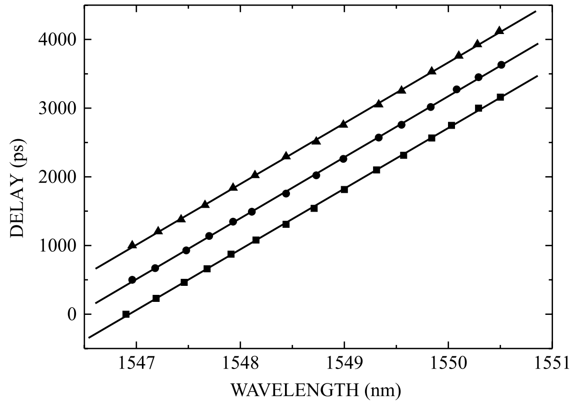

Fig. 3. Group delay of the line versus the wavelength measured with different filters: (■) g1; (●) g2; (▲) g3. Modulation frequency, 6 GHz.

888 ± 4 and 886 ± 4 ps/nm, while the dispersion calculated from Fig. 2 which has been measured feeding the chirped grating with a tunable laser is 880 ps/nm, so the differences are below 0.5% in the three cases.

Similar results have been found with other modulation frequencies within the range (0.5–6) GHz. The phase dependence on the modulation frequency using filter g1 is presented in Fig. 4. The phase has a linear variation with the microwave frequency and the group delay of the line can be

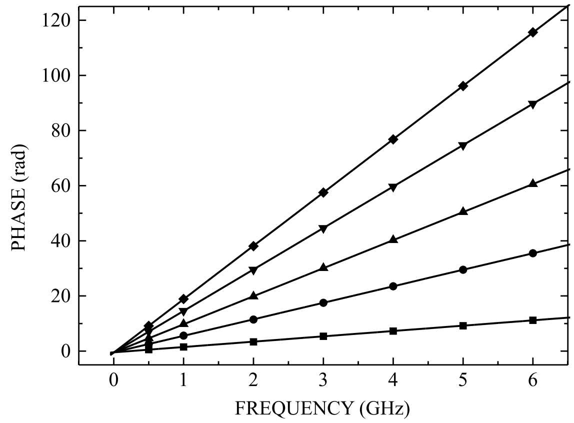

Fig. 4. Phase of the microwave signal as a function of the modulation frequency at different optical wavelengths: (■) 1547.19 nm; (●) 1547.91 nm; (▲) 1548.71 nm; (▼) 1549.57 nm; (◆) 1550.29nm. Filter, g1.

tuned with the wavelength of the optical carrier. The group delay obtained from different curves in Fig. 4 are 0.3075, 0.9535, 1.619, 2.393 and 3.079 ns with an RMS error of 0.4%. The same linear behaviour has been observed using as filters the other two gratings.

The amplitude response is shown in Fig. 5 where the performance of the system fed by a fiber grating is compared with the system fed with a tunable laser. We see a signal cancellation at 8.5, 14.7 and 18.9 GHz and there is an additional decay and a new notch at 14.0 GHz. Fig. 6 shows the amplitude performance of the system with different filters, the increasing bandwidth of the filters results in a reduction of the microwave operating range. For better understanding of this behaviour we can consider the chirped grating as a phase filter with transfer function $H(\omega) = \exp(\mathrm{j}\phi(\omega))$ with

$$\phi(\omega) \approx \phi(\omega_B) + \tau(\omega_B)(\omega - \omega_B) + \beta/2(\omega - \omega_B)^2,$$

where ω_B is the central wavelength of the amplitude filter $\rho(\omega)$, in such a case Eqs. (1) and (2) become:

$$E(\Omega) = m\left|\int_{-\infty}^{+\infty} |\rho(\omega - \omega_B)|^2 \mathrm{e}^{\mathrm{j}\beta\Omega(\omega-\omega_B)}\,\mathrm{d}\omega\right| \times \cos\left(\frac{\beta\Omega^2}{2}\right), \quad (3)$$

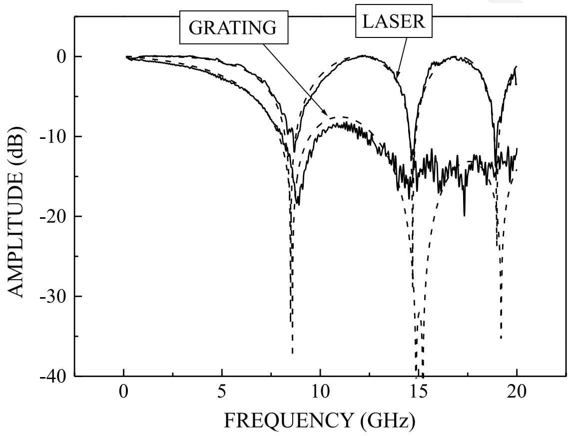

Fig. 5. Amplitude of the microwave signal as a function of the modulation frequency. Comparison of the system fed through grating g1 and fed directly with a tunable laser. Both cases include measured data (solid line) and theoretical prediction (dashed line).

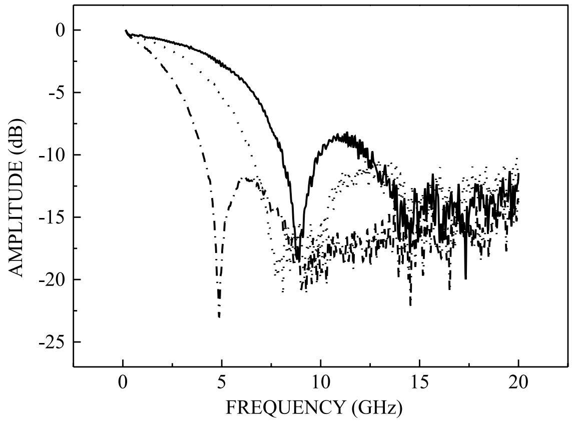

Fig. 6. Amplitude of the microwave signal measured with different filters. Solid line, filter g1; dotted line, filter g2; dashed line, filter g3.

$$\Psi(\Omega) = -\tau(\omega_B)\Omega. \quad (4)$$

Eq. (3) has three factors: the modulation depth, the Fourier integral of the amplitude filter $\rho(\omega)$ and the carrier suppression factor of AM modulated systems $\cos(\beta\Omega^2/2)$. Hence the microwave frequency range Ω_{max} is limited by the bandwidth of the grating $\Delta\omega$ to $\Omega_{max} = 2.5/(\beta\Delta\omega)$, and by carrier suppression effect to $\Omega_{max} = (2\pi/3\beta)^{1/2}$.

The amplitude performance of the system could be improved in two ways: by using a different modulation technique and by reducing the bandwidth of the filter. The first notch in the amplitude response at 8.5 GHz (see Fig. 5) could be suppressed by using a SSB + carrier modulated signal [11]. The second notch at 14.0 GHz appears because of the bandwidth of the filter and it can be shifted to higher frequencies by using gratings with narrower reflection bands. By combination of SSB modulated light and a filter of 0.05 nm bandwidth we expect to have a system with a first notch beyond the Ku microwave band.

This system has a reduction in the dynamic range with respect to systems using laser sources because the low power level reflected by the filters. Using a fluorescent doped fiber as light source at 1500 nm or superluminescent diodes at 1300 nm and at 1500 nm the spectral energy density is about

−10 dBm/nm or even more; after filtering with a 0.05 nm bandwidth grating, the available power is about −23 dBm/nm that can be used without amplification in many applications.

Finally we must point out that the use of a tunable light source as presented in this paper is particularly suitable for microwave devices based on fiber gratings because the system can be thermally stable. Packaging together the filter and the device under test both will suffer the same temperature variations and consequently the system should exhibit a passive compensation of temperature effects.

3. Conclusions

We have studied the behaviour of fiber Bragg gratings as filters of white light sources for driving microwave photonic devices. The system has a good phase response but the amplitude performance is limited by the bandwidth of the filter and by the carrier suppression effect in amplitude modulated systems. The device we have tested in these experiments presents a correct behaviour from 0.5 to 6 GHz and can be optically tuned in a range of 4 nm.

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References

[1] A. Seeds, IEICE Trans. Electron. E76-C (2) (1993) 198.
[2] G. Yu, W. Zhang, J.A.R. Williams, IEEE Photon. Technol. Lett. 12 (9) (2000) 1183.
[3] G.A. Ball, W.H. Glenn, W.W. Morey, IEEE Photon. Technol. Lett. 6 (6) (1994) 741.
[4] R.A. Minasian, K.E. Alameh, IEEE Trans. Microwave Theory Tech. 45 (8) (1997) 1513.
[5] J.L. Cruz, B. Ortega, M.V. Andrés, B. Gimeno, D. Pastor, J. Capmany, D. Pastor, L. Dong, Electron. Lett. 33 (7) (1997) 545.
[6] W. Zhang, J.A.R. Williams, L.A. Everall, I. Bennion, Electron. Lett. 34 (18) (1998) 1770.
[7] H. Zmuda, R.A. Soref, P. Payson, S. Johns, E.N. Toughlian, IEEE Photon. Technol. Lett. 9 (2) (1997) 241.
[8] D.A. Cohen, Y. Chang, A.F.J. Levi, H.R. Fetterman, I.L. Newberg, IEEE Photon. Technol. Lett. 8 (12) (1996) 1683.
[9] B. Ortega, J.L. Cruz, J. Capmany, M.V. Andrés, D. Pastor, J. Lightwave Technol. 18 (3) (2000) 430.
[10] J. Capmany, D. Pastor, B. Ortega, Electron. Lett. 35 (6) (1999) 494.
[11] J.L. Corral, J. Marti, J.M. Fuster, R.I. Laming, Electron. Lett. 34 (2) (1998) 209.